PATENT SPECIFICATION

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DRAWINGS ATTACHED

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(54) METHOD FOR SUPPLYING ELECTRICITY TO A HEAT-GENERATING PIPE UTILIZING SKIN EFFECT OF A.C.

(71) We, CHISSO CORPORATION, of 1 Sozecho Kitaku, Osaka, Japan, a Japanese Body Corporate, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

THIS INVENTION relates to a method for supplying electricity to a heat-generating pipe which utilizes the skin effect of A.C., and to an A.C. load.

The invention resides in a method for supplying electricity to at least one heat-generating pipe of ferro-magnetic material and to an A.C. load alternatively, which method comprises connecting the end of said heat-generating pipe remote from an A.C. supply source to a plurality of conductor lines connected to the A.C. supply source, the said lines being supported within said heat-generating pipe in its longitudinal direction in electrically insulated relation from the inner wall of said heat-generating pipe, and simultaneously connecting the plurality of conductor lines to the A.C. supply source and connecting the other end of said heat-generating pipe to said A.C. supply source to enable current to flow only through the inner wall portion of said heat-generating pipe and to generate therein heat which is transmitted through the outer wall portion of said heat-generating pipe, and subsequently breaking the connection of the conductor lines at both ends of said heat-generating pipe while connecting said A.C. supply source through said plurality of conductor lines to said A.C. load.

The plurality of conductor lines may for example comprise three conductor lines for three-phase A.C. or two lines for single-phase A.C.

Alternating current may be supplied to a heat-generating pipe through one or more insulated conductor lines accommodated in said heat-generating pipe and simultaneously to an A.C. load through insulated conductor lines accommodated in another heat-generating pipe, or alternating current may be supplied at one time to a heat generating pipe through insulated conductor lines accommodated in said heat-generating pipe and at another time to an A.C. load through said insulated conductor lines.

Apparatus for maintaining liquid being transporter in a pipe line at an elevated temperature which utilizes the skin effect of alternating current flowing in a heat-generating ferromagnetic pipe, is described in U.S. Patent 3,293,407.

The principle of such a ferromagnetic skin-effect heat-generating pipe will now be described. A conductor, e.g. an insulated electric wire, extends between the ends of the pipe and is electrically insulated from the pipe, one end of which conductor is connected to an A.C. supply source and the other end of which is connected to a terminal of the pipe. When an A.C. electric potential is supplied from the A.C. supply source to the circuit consisting of the conductor and the pipe, the current flowing in the material of the pipe appears only at the skin part of the inner wall portion of the pipe, as is well known, and alternating current tends to flow only in the skin of the conductor carrying it. In the case where this conductor is a pipe containing a conductor carrying current in the opposite direction, the magnetic interaction between the opposite currents tends, as is well known, to draw the currents together, with the result that the current in the pipe is concentrated in the inner skin part of the pipe wall.

The region in which the current flows is called the penetration depth. Let this be s (cm), inner diameter of the pipe be d (cm) and if $d \gg s$, s can be expressed approximately by

$$S=5030\sqrt{\frac{\rho}{\mu f}}$$

in which ρ is the specific resistance of the pipe material (Ωcm), μ is its magnetic permeability, and f is frequency (cycles/sec.). Further if the pipe thickness t (cm), penetration depth s (cm), and length l (cm) satisfy the relations $t > 2S$ and $l \gg D$, the current concentrates in the skin part of the inner wall portion of the pipe 2 and no current appears in the outer surface zone of the pipe. Thus heat is generated by the current in the skin part of the inner wall portion of the pipe, and is transmitted to the outside of the pipe through the pipe wall and can then be utilized in heating various objects.

When a steel pipe and commercially available a.c. of 50 or 60 c.p.s. are used, the value of S calculated from the above-mentioned formula becomes approximately 0.1 cm. Since a pipe thickness of 0.2 cm. will be sufficient to satisfy the above-mentioned conditions, there is no need to select a special pipe material or a.c. frequency. Such a heat-generating pipe may be installed beside a liquid-transporting pipe line to be heated. For example, three heat-generating pipes may be fixed over the entire length of the pipe line in substantially axially parallel relationship therewith.

However, in the case of a pipe line of large capacity, such as those used in the transportation of crude oil, heating is necessary only before starting the transportation of liquid. During the transportation of liquid, since the temperature in the inside of the pipe line is maintained approximately constant by the sensible heat of the liquid being transported, there is little or no need of heating. Accordingly, the installation cost of the heat-generating pipe is expensive relative to its short working time, and it is desirable to reduce the installation cost.

The present invention will be further described with reference to the accompanying drawing, in which:

Figure 1 is a schematic circuit diagram of one embodiment of the present invention, and Figure 2 is a cross-sectional view of a heat-generating pipe which utilizes the skin effect of A.C., installed in contact with a long-distance liquid transportation pipe.

As shown in Figure 2, three identical heat-generating pipes 1, 2, 3 are disposed parallel to and in contact with a pipeline 22. Pipes 2 and 3 contain respective insulated conductors 5, 6 and pipe 1 contains three insulated conductors 4, 4′, 4″ for carrying three-phase a.c.

One end of each conductor 5, 6 can be connected to a respective phase of a three-phase a.c. source 20, by means of switches 9, 10. Each pipe 1, 2, 3 is connected at its end nearer source 20 to the a.c. neutral conductor 19, by means of terminals 13, 15, 17. At their other, remote ends pipes 2, 3 are connected at terminals 14, 16 to their conductors 5, 6.

Pipe 1 is connected at terminal 13 to neutral conductor 19, but its remote end terminal 12 is connected to a switch 7 by means of which terminal 12 can be connected to conductors 4, 4′, 4″ in parallel. The ends of the latter conductors nearer the source 20 can be connected in parallel to the third phase of the source by a switch 18.

Thus when switches 9, 10, 7, 18 are closed a.c. will flow in the inner skin parts of pipes 1, 2, 3 owing to the skin effect and thereby heat them.

It will be seen that the remote ends of the pipes are earthed for safety. This earthing does not short circuit the current in the pipes because the earth impedance seen by the conductor 4, 5 or 6 is high in relation to the impedance presented by the pipe itself.

By means of a switch 8 the nearer ends of conductors 4, 4′, 4″ can be connected to respective phases of source 20. The remote ends of these conductors are connected to respective primary terminals of a transformer 21 supplying a motor 11 of a pump for transporting liquid through pipeline 22. Thus when switches 7, 18 are open and switch 8 is closed, three-phase a.c. power is supplied to drive the pump to transport liquid through pipeline 22 towards source 20.

Before transportation of liquid begins, the heat-generating pipes 1, 2 and 3 are all used for the purpose of heating. In the case of 1, by opening switch 8 and closing switches 7 and 18, A.C. flows through separate lines 4, 4′, and 4″ to the remote end of the heat-generating pipe 1 and flows through the skin part of its inner wall portion. When the temperature of the liquid in the pipe line 22 has been elevated to a desired value, the heating is stopped, and transportation of liquid is started by opening the switches 18 and 7 and closing the switch 8 so that three phase A.C. flows through the lines 4, 4′ and 4″ and pump motor 11 is energized. If the three currents are balanced and there is no zero phase current, there will be no eddy current or heat generation in the pipe, as in the case of a common pipe used as a cable sheath. The conductors 5, 6 in the pipes 2 and 3 are de-energized but if necessary it is possible to supply electricity in order to use them for heating. Further by making the arrangement of the conductor lines in these pipes the same as in pipe 1, it is possible

to use these pipes for power supply. Though Figure 1 illustrates a case where the load requires three phase A.C., it goes without saying that a similar arrangement can be made in the case of single phase A.C. Transformer 21 is used to change the voltage, when the voltage of the load is not the same as that of the circuit of the heat-generating pipe, i.e. that of the supply source. It is possible to instal a tertiary winding on the transformer for use with a relay 23 in order to open the switch 7 automatically when switch 8 is closed and switch 18 is opened, and to close switch 7 when the single-phase voltage is applied to pipe 7 for heating. Thus the relay and switch 7 are remote controlled and the shift between heating and liquid transportation can be carried out safely even when the motor 11 is installed at a location remote from the A.C. supply source.

As a most suitable application of the invention, the case of crude oil transportation from an oil well in the sea bed can be considered. In order to make the equipment in the sea as simple as possible, only oil transporting, i.e. pumping, equipment is laid there, and an A.C. supply source, other auxiliary equipment, and controlling means are placed on the land near the beach. There are many crude oils having high viscosity, and even when they have fluidity at the time of drawing up due to the heat of the earth, they become viscous during transportation. Unless heated, they cannot be transported.

The invention is particularly effective in pipelines used in the transportation of such oils. The elimination of a separate feeder line from the A.C. supply source to the pump or other load (e.g. lighting equipment) gives economic advantages, increasing with the increase of the length of the pipeline.

The present invention might be thought to be applicable to other heat-generating methods but in reality, only heat generation utilizing the skin effect of A.C. is effective. With other heat-generating methods e.g. M.I. (mineral insulated) cable which uses a cable insulated with an inorganic substance, all the heat generated comes from the electric cable and the total potential drop occurs in the electric cable. If the load requires the same current as the heating, the potential at the load becomes zero and the load cannot receive electric power from the supply source. Accordingly, for example, in order to obtain at the load an electric potential corresponding to 90° of the supply, the current must be only approximately 1/10 of the current used for heating, and as a feeder to the load, the conductor line will be of exceedingly small capacity. In the present invention, nearly 90% of the heat generated comes from the body of the heat-generating pipe and only 10% of it is produced in the conductor line. Accordingly, the potential drop in the conductor line is also only about 10%. Even when a load requires the same quantity of current as in the case of heating, the conductor line has a sufficient capacity as a feeder.

It is desirable to take measures to increase heat conduction from the heat-generating pipe to the liquid transporting pipe by contact or welding, when the heat-generating pipe is used to heat liquid in the transporting pipe.

Further, it is very effective to fill, with a fluid having a heat conductivity greater than that of air, the space within the heat-generating pipe, because the allowable current for an insulated conductor line accommodated in a heat-generating pipe is dependent upon the allowable temperature of the insulating material used in the conductor line, the temperature of the insulating material is reduced with the increase of the heat of the material existing in the clearance part of the pipe, and the filling of heat-conductive fluid therefore increases the allowable current in the conductor line. As heat-conductive liquid useful for the above-mentioned purpose, water, or an aqueous solution of a salt such as sea water, is preferred but oils, fats, petroleum oils, alcohols, and aqueous solutions of the foregoing are also effective. When the insulated conductor line is an insulated cable for high voltage use, the electric field intensity around the surface of the insulated material can be made uniform and hence the durability of the insulating material can be improved by selecting a relatively electrically conductive material from among heat-conductive liquids useful in the filling the clearance part of the pipe.

WHAT WE CLAIM IS:—

1. A method for supplying electricity to at least one heat-generating pipe of ferromagnetic material and to an A.C. load alternatively, which method comprises connecting the end of said heat-generating pipe remote from an A.C. supply source to a plurality of conductor lines connected to the A.C. supply source, the said lines being supported within said heat-generating pipe in its longitudinal direction in electrically insulated relation from the inner wall of said heat-generating pipe, and simultaneously connecting the plurality of conductor lines to the A.C. supply source and connecting the other end of said heat-generating pipe to said A.C. supply source to enable current to flow only through the inner wall portion of said heat-generating pipe and to generate therein heat which is

transmitted through the outer wall portion of said heat-generating pipe, and subsequently breaking the connection of the conductor lines at both the ends of said heat-generating pipe while connecting said A.C. supply source through said plurality of conductor lines to said A.C. load.

2. A method according to claim 1 wherein the clearance between the heat-generating pipe and the conductor lines is filled with a heat-conductive material.

3. A method according to claim 1 or 2, wherein the plurality of conductor lines comprises three conductor lines for three phase A.C.

4. A method according to claim 1 or 2 wherein the plurality of conductor lines comprises two lines for single phase A.C.

5. A method according to claim 1, 2, 3 or 4 wherein the A.C. load is a motor for a pump for liquid being heated.

6. A method for supplying electricty to at least one heat-generating pipe of ferromagnetic material and to a load alternatively, substantially as herein described and illustrated in the accompanying drawing.

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1,204,405 COMPLETE SPECIFICATION
1 SHEET This drawing is a reproduction of the Original on a reduced scale.

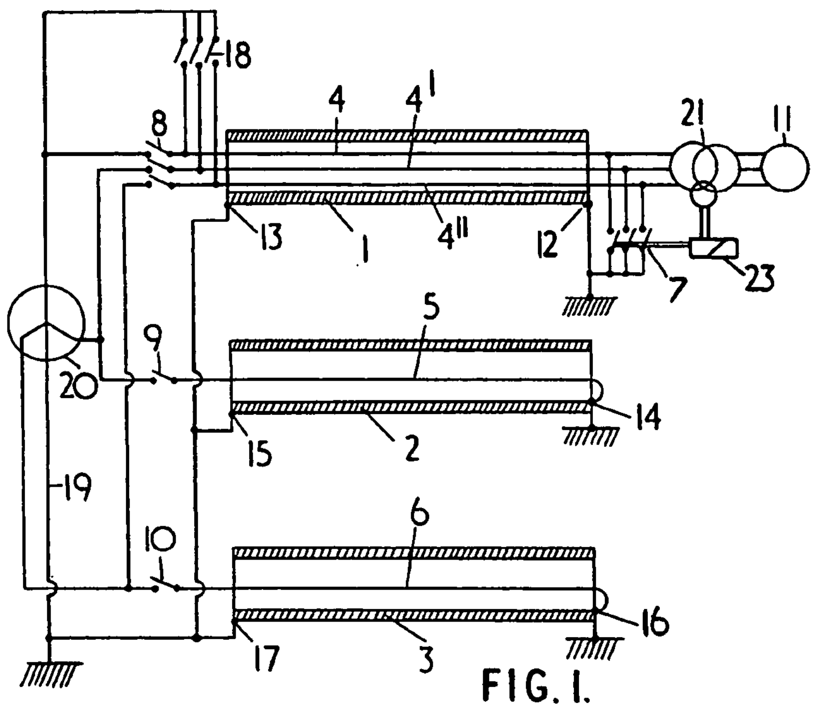

FIG. 1.

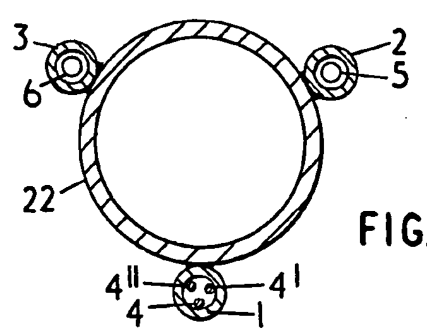

FIG. 2